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(54) **Aperture coupled output network for ceramic resonator and cavity resonator combiner network**

(57) A novel junction design was developed for use with in-line combiner networks to minimize electrical length between the resonators being combined and to optimize coupling. It consists of a combiner comprising a plurality of cavity resonators coupled to a combining mechanism. The combining mechanism is placed outside of each resonator a prescribed distance above the ground plane. Combiner pairs are created by connecting two cavities to each other using quarter-wave lines. The central combiner pair is directly connected to the output connector through a common port The quarter-wave junctions not directly connected to the output connector are then connected to the output port through half-wavelength lines. Iris or aperture coupling is controlled by a sliding cover that is adjusted using a free-rotating screw and is secured with locking screws to ensure good electrical and RF grounding.

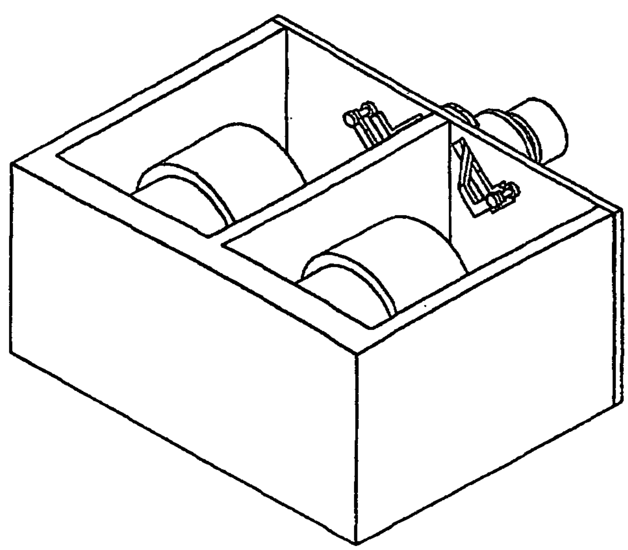

Figure 2.

EP 1 294 043 A2

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Description

FIELD OF THE INVENTION

[0001] The invention is related to the field of combiners. More particularly, this invention relates to inline combiner networks which combine multiple frequency sources.

BACKGROUND OF THE INVENTION

[0002] Figures 1 and 2 illustrate a combining network having two cavity resonators which uses intrusive coupling loops to couple signals from the different resonators. This approach has been used with ceramic, waveguide, and coaxial resonators. Coupling of a signal from each cavity is achieved in the following manner. A loop is placed into the cavity such that it couples into the magnetic field of the desired mode. The two loops (one for each cavity) are then joined at a common terminal and connected to the antenna port.

[0003] Figure 3 shows a schematic of a general two-channel cavity combiner. The resonators are treated as a parallel LC resonator that is mutually coupled to two ports. The input port is connected - usually through an isolator - to a transmitter. The output port is connected to a junction via a transmission line, and a shunt component is attached at the junction to remove excess inductive reactance.

[0004] The resonator itself is used to pass the primary frequency while rejecting other frequencies by a certain amount.

[0005] The frequency response of a cavity centered at a frequency f_0 is given in equation 1:

$$(1) \qquad H(f) = 1 - \frac{Q_L}{Q_U} \cdot \frac{1}{\sqrt{1 + \left(2 \cdot Q_L \cdot \frac{f - f_0}{f_0}\right)^2}}$$

where Q_L is the ratio of the center frequency of the resonator to the frequency separation between the half-power (3 dB) points and is a function of the cavity coupling. The term Q_U is the unloaded Q of the resonator and represents the resonator Q if there was no external loading. The ratio of loaded Q to unloaded Q is the reflection coefficient at the center frequency of the resonator due to the internal losses of the resonator. The closer the ratio is to unity, the higher the loss in the cavity at midband. An important tradeoff in cavity performance is between narrow bandwidth and low loss.

[0006] The electrical length of the lines separating the resonators from the junction is determined from transmission-line theory. In transmission-line theory, it is widely known that an ideal line of length L transforms a load whose admittance is Y to an admittance Y_B such that:

$$(2) \qquad Y_B = Y_0 \cdot \frac{\left(\cos\left(2 \cdot \pi \cdot \frac{L}{\lambda}\right) \cdot Y + 1i \cdot \sin\left(2 \cdot \pi \cdot \frac{L}{\lambda}\right) \cdot Y_0\right)}{\left(\cos\left(2 \cdot \pi \cdot \frac{L}{\lambda}\right) \cdot Y_0 + 1i \cdot \sin\left(2 \cdot \pi \cdot \frac{L}{\lambda}\right) \cdot Y\right)}$$

where Y_0 is the characteristic admittance of the transmission line, and λ is the wavelength in the transmission line. This equation is found as equation 14 in Ramo, S; Whinnery, J.; Van Duzer, T.; Fields and Waves in Communications Electronics, 3rd Edition., 1994, John Wiley & Sons, New York, pp229 - 232, p254 - 256, hereby incorporated by reference. The transmission line can be several different shapes, such as coaxial or parallel wire. The embodiment we use uses a air-dielectric microstrip line designed such that the characteristic impedance Z_0 is 50 ohms, which corresponds to a characteristic admittance Y_0 of $1/Z_0$ or 0.02 mhos.

[0007] One of the well known property of ideal transmission lines is that the impedances tend to repeat themselves every half-wavelength. For example, a shorted transmission line ($Y \rightarrow \infty$) acts like an open circuit when the distance from the short is $\lambda/4$- one quarter wavelength. When the distance reaches $\lambda/2$ - one half wavelength - the admittance is that of short-circuit again. The impedance curves can be found in Pozar, D.; Microwave Engineering, 1993, Addison Wesley, New York, pp 76-84, hereby incorporated by reference. In the case where the admittance is Y, the transformed admittance Y_B is given in equation 3.

$$(3)\quad Y_B = \frac{{Y_0}^2}{Y}$$

[0008] Equation 3 shows that the quarter-wave transmission line acts as an admittance inverter because the higher admittances become low admittances at the opposite end of the transmission line.

[0009] The admittance of the isolated resonator loaded on the output with a load with admittance Y_0 is approximately given as equation 4.

$$(4)\quad Y = Y_0 \cdot \left(1 + \frac{Q_L}{Q_U}\right) \cdot \left(1 + 2j \cdot Q_L \cdot \frac{f - f_0}{f_0}\right)$$

[0010] Equation 4 shows that the admittance Y becomes very large as the frequency f becomes more distant from f_0. This means that an ideal parallel resonator becomes a short circuit at frequencies far from resonance, and a quarter-wave resonator will transform the near-short circuit.

[0011] Using the preferred embodiment as shown in figure 3, the resonators are set for center frequencies of f1 for the TX1 cavity and f2 for the TX2 cavity. In an ideal parallel-cavity resonator, the electrical length of the loop would be zero, and the cavity resonator's off-resonance admittance would approach the infinite conductivity of a short circuit as the TX2 resonator frequency becomes further from f2. In such a case, attaching a transmission line of a quarter-wavelength would make the cavity look like a very low admittance and approach an open-circuit off the resonant frequency of the cavity at the other end of the cable.

[0012] If this admittance was placed in parallel with the antenna which is assumed to have an admittance of Y_0, then the additional "shunting" loss α_{sh} caused by the joined cavity is given in equation 5.

$$(5)\quad \alpha_{sh} = \left| \frac{2}{2 + \frac{Y_B}{Y_0}} \right|$$

[0013] As the magnitude of the Y_B/Y_0 ratio approaches zero, the shunting loss approaches zero. This is expected since an open circuit in parallel with any admittance has no effect on said admittance. If a second cavity on a frequency sufficiently separated from the first cavity is also attached to a quarter-wave transmission line, they can be joined to a common output. The first cavity on its resonant frequency only sees a small additional loading from the second cavity and vice versa.

[0014] As equation 4 shows, the cavity's frequency response has an effect on the admittance off resonance or off the cavity's resonant frequency. However, the combiner can still be used to combine cavities as long as the frequency separation between cavities is such that the response of one cavity frequency on the neighbor's cavity response is down 4-6 dB from the center of the response. In such a case, the shunting loss approaches 1.3 dB. The shunting loss can be as high as 1.5 dB with multiple channels and still be useable in most systems where frequency separations are tight.

[0015] Ideally, the two loops in figures 1 and 2 should be separated electrically from the junction by a transmission line whose length is one-quarter of a wavelength. In such a case, the shunt reactance shown in figures 3 and 4 would be unnecessary. Unfortunately, an exact quarter-wave line is difficult to define or achieve. For example, all cavities have some small inductive reactance due to the finite length of the loop. Figure 3 shows the general case where the line separating the cavities in the combiner is less than - but fairly close to - a one-quarter-wavelength transmission line. The schematic includes the inductive reactance of the loop. Though not an exact quarter-wave line length, the two resonators can be connected as shown as long as the internal shunt reactance at the junction is cancelled using a shunt network. In the case where the separating lines are less than a quarter-wave in length, the internal shunt reactance at the junction is cancelled using a capacitor C_{bal} is shown in figure 3.

[0016] The main difficulty with using internal loops to couple signals from the cavity resonator is the electrical length required to reach the strong field region - particularly in ceramic resonators. Because of the cavity size, the loop become so long that the lines are longer than quarter-wave. In the case where the lines are longer than a quarter-wavelength but less than a multiple of a half-wavelength, a shunt inductor is required to cancel the internal shunt reactance. In the case shown in figure 4, a fixed shunt inductor L_{bal} was chosen to be a fixed value and a shunt capacitor C_{bal} is placed across the inductor to electrically cancel the combined reactance of the balancing inductor and the residual reactance

from the cavities and network. Further, the additional electrical length reduces the tuning range of the combiner because the lines are electrically longer and the inductor - usually implemented as a shorted transmission line stub - has a frequency dependence that further limits the useable range of the combiner.

[0017] Looking again at equation 1, Y_B equals Y whenever the cosine terms become 1 and the sine terms become zero. These occur at zero-length and at half-wavelength intervals. In the zero-length case, the two cavity outputs would be directly connected at the output, and the output signal from said cavity would be loaded down by the reactance and conductance of each adjacent cavity. A balancing capacitor can be added - similar to what is shown in figure 3 - but the cavities would still be, in essence, in parallel. As a result, more than half of the power going into one cavity would end up either reflected back or go directly into the adjacent cavity and out to the other input. This is a very undesirable condition. From equation one, it is seen that this condition also occurs if the cavities are combined using half-wavelength transmission lines. Again, there is no way to compensate this network. Consequently, it is preferable that the effective length from the cavity output to the junction not be a multiple of a half-wavelength. Thus, using a half-wave transmission line to couple energy from each cavity, the loops are effectively in parallel and there is low isolation between cavities.

[0018] Another issue with the loop design is that the only means of adjusting the coupling from the cavity is by adjusting the height of the loop. Sometimes, the loop has to be adjusted for optimal combiner/cavity performance. To make the adjustment, one has to loosen the ground side of the loop, move the ground up or down using a tool that protrudes into the cavity, retighten the locking hardware, and then make a measurement to determine if further adjustment is required. This approach is time consuming because the measurement is not accurate until the loop is tightened. In addition, sometimes the loop moves during the adjustment process. This results in the loop having to be adjusted additional times.

[0019] Another approach disclosed in the prior art was to use a common coaxial resonator to couple electromagnetic energy from each of the cavity resonators. A resulting standing wave in the common coaxial resonator couples into each cavity through apertures, one for each cavity resonator. The apertures are located a prescribed distance along the resonator transmission line as shown in a cut-away view in figure 5.

[0020] This approach works well if the electrical length between cavities is in half-wave increments. This is the case if the common resonator is a multiple half-wavelength coaxial resonator. In that case, the coaxial resonator's length is a multiple half-wavelength of the average frequency of the combiner. Stated another way, the physical length of the coaxial resonator is a multiple half-wavelength of the average frequency of the input signal comprising a plurality of microwave signal frequencies output at the output port. Using half-wave increments, the signals are, effectively, combined in parallel. Therefore, the coaxial resonator appears as a low impedance to any of the input channel frequencies.

[0021] Unfortunately, in many cases there are restrictions on the length of the combiner such that that half-wave physical spacing is very difficult to achieve. Furthermore, the shunt reactance at the output junction or port would be difficult to predict. Consequently, a complicated compensating network would be needed to balance the phases of the different signals. In addition, low-loss combining would be difficult in that configuration.

[0022] Furthermore, even if there was enough room to electrically space the apertures by a half-wave, the outer channels would be very long electrically. For example, a six-channel unit would have its outer channels with 1.25 wavelengths between the aperture and the output.

[0023] That would limit the bandwidth of the junction rather dramatically since only very high frequencies could be combined due to the reciprocal relationship between frequency and wavelength, i.e., the higher the frequency, the shorter the wavelength.

SUMMARY OF THE INVENTION

[0024] In a preferred embodiment, the invention is a combiner comprising a common port, a plurality of cavity resonators, a plurality of apertures and a combining mechanism operably connected to the common port and coupled to the plurality of resonators through apertures.

[0025] In another preferred embodiment, the combining mechanism comprises a junction to combine signals from a pair of cavity resonators. Transmission lines a quarter-wavelength or less in length connect the junction to the apertures.

[0026] In still another preferred embodiment, the invention comprises at least one edge pair of cavity resonators and a central pair of cavity resonators. The outputs of the edge pair of resonators are connected to a common port through half-wave transmission lines. The center pair of resonators are connected to the common port.

[0027] In still another preferred embodiment, the invention further comprises sliding covers located over the apertures to adjust coupling. A free-rotating screw adjusts the aperture by moving the sliding cover. The sliding covered is secured using at least one locking screw.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028]

Figure 1 is a drawing of a two-channel ceramic combiner utilizing loop coupling with a network cover removed for clarity.

Figure 2 is a reverse view of a ceramic combiner with loop coupling with cavity cover removed for clarity.

Figure 3 is a schematic of a two-channel combiner with sub-quarter wave lines combining outputs.

Figure 4 is a schematic of a two-channel combiner with longer lines combining outputs.

Figure 5 is a cut-away view of a ceramic resonator using common output coaxial resonator.

Figure 6 is a drawing of a two-channel ceramic combiner utilizing aperture coupling with cover removed for clarity.

Figures 7a and b are a front and a top view of a two-channel combiner junction with covers removed for clarity.

Figure 8 is a front view of a two-channe 1 combiner using a novel junction.

Figure 9 is a drawing of a six-channel ceramic combiner utilizing a novel junction with cover removed for clarity.

Figure 10 is an exploded view of a six-channel network applied to a ceramic resonator combiner.

Figures 11a and b are a front and a top view of a combiner network. The cover and capacitor are removed for clarity.

Figure 12 is drawing of a waveguide in-line combiner utilizing a novel junction design.
The cover is removed for clarity.

Figure 13 is a drawing of a four-channel central junction waveguide combiner utilizing a novel junction design. The cover is removed for clarity.

DETAILED DESCRIPTION OF ONE EMBODIMENT OF THE INVENTION

Two Channel Combiner

[0029] A novel junction design was developed for use with in-line combiner networks to minimize electrical length between the resonators being combined and to optimize coupling. It utilizes a shunt fed iris on each channel to couple electromagnetic energy from the cavity resonator to and from an output port. In addition, it combines adjacent cavity outputs in a semi-binary fashion similar to the integrated loop junction. The output of the edge pairs are connected to the central junction or common port through half-wave transmission lines while the center pair is directly connected to the output.

[0030] The invention is a combiner comprising at least one pair of cavity resonators. The two cavities in each combiner pair are connected to each other using quarter-wave lines. The quarter-wave line length acts as an admittance inverter and transforms the low impedance of each cavity resonator to a high impedance at the junction of the combiner pair. Therefore, the pair of resonators have high isolation between eachother. The quarter-wave junctions of the central pair are directly connected to the output port.

[0031] In another embodiment, the invention comprises a common port, two edge pair of cavity resonators and a central pair of cavity resonators for a total of three pair of cavity resonators or six channels. The quarter-wave junctions of the two edge pair of cavity resonators are connected to the output port through half-wavelength lines.

[0032] Using half-wavelength lines between quarter-wave junction outputs has the effect of putting the three pairs essentially in parallel. That is, the impedance seen at a half-wavelength from the quarter-wave junction is the same as the impedance directly at the quarter-wave junction. Consequently, the three quarter-wave junctions are effectively shorted together. Therefore, there is minimal phase difference between the three signals. Consequently, by keeping the line length between the pairs to a half wavelength or a multiple of a half wavelength, a single balancing capacitor C1 can be used to cancel any residual shunt reactance.

[0033] Figures 6, 7, and 8 show a two-channel ceramic combiner 1 utilizing the novel design. The present invention

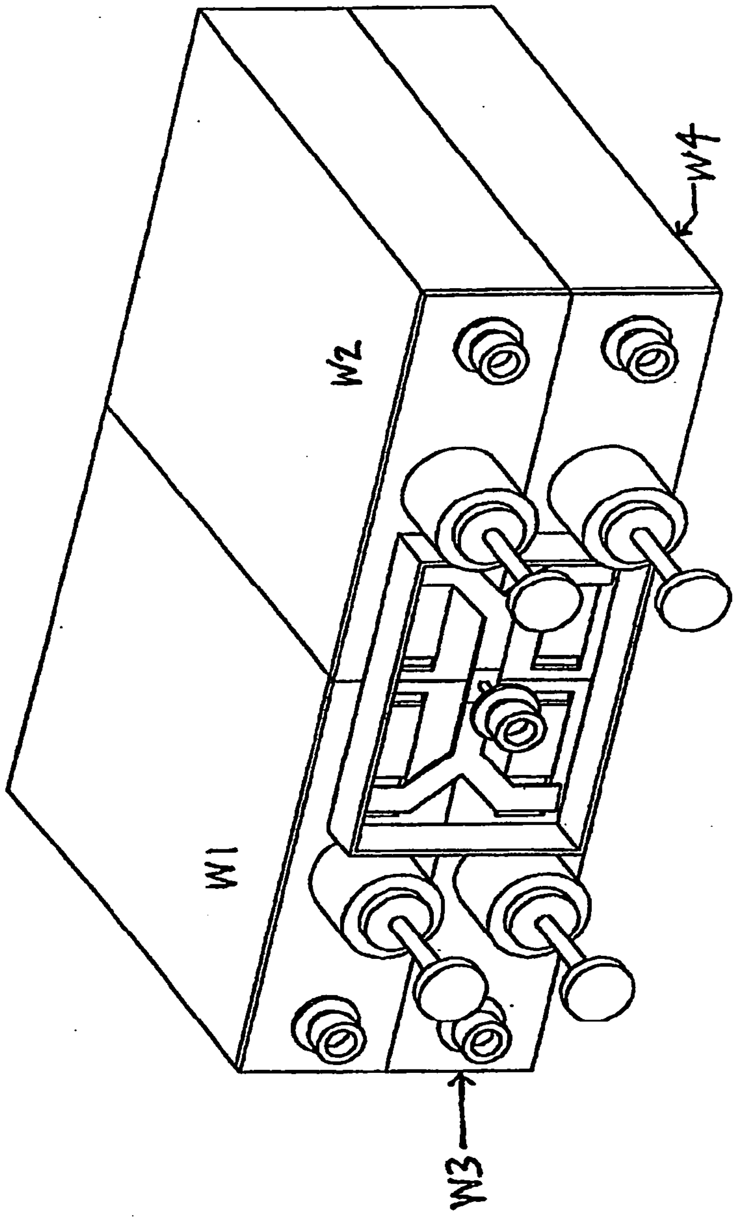

FIGURE 13.

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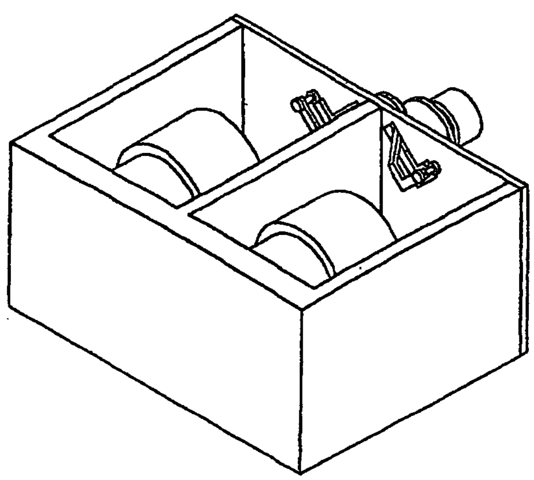

Figure 2.

EP 1 294 043 A3